Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines

(Thirteenth Annual Report)

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Executive Summary

Pursuant to Senate Joint Resolution No. 126 of the 1985 Session and Senate Joint Resolution No. 278 of the 1993 Session, this thirteenth annual report on monitoring of ongoing research on the human health effects of high voltage transmission lines is submitted to the members of the 1998 Virginia General Assembly. Since the submission of the last report, entitled "Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Twelfth Annual Report)," dated March 20, 1997, several articles, reports, and reviews have become available in the literature on this subject. An overview of these publications is presented in this report.

The possible health effects of electromagnetic fields (EMF) exposure in an occupational environment were first reported in the literature from the former Union of Soviet Socialist Republics (USSR) in the mid-1960s. Several subjective complaints, involving the cardiovascular, digestive, and central nervous systems, were reported by electric switchyard workers. Subsequent studies of electric utility linemen in the United States failed to observe the same adverse health effects reported by their counterparts in the former USSR. Since that time, scientific interest has continued to increase in an attempt to ascertain an association between residential and occupational exposures to EMF and detrimental health effects.

Over the past several years, burgeoning public concerns, as well as scientific uncertainty regarding potential health effects from exposure to power frequency EMF emanating from nearby high voltage electrical transmission lines, have generated considerable controversy among scientists, courts, regulatory bodies and public policy makers. Since 1979, numerous epidemiologic studies have appeared in the literature exploring a possible causal association between exposure to EMF and cancer, especially leukemia and brain tumors. Nonetheless, the subject still remains controversial. This is because the results of these investigative studies have been contradictory, inconclusive, and far from establishing an unequivocal dose-response or a cause-effect correlation. Some investigators have suggested statistically significant, but weak positive associations between EMF and the increased risk of cancer from occupational exposure or proximity to high voltage transmission lines. The relative risk inferred in some of the studies is low in magnitude and is within the range where experimental bias or confounding factors cannot be completely ruled out. The reported incremental increases in cancer incidence are also discordant with respect to cancer types or site. The reported increases in risk have been observed only in relation to estimates of magnetic fields based on extrapolation of historical data, but not to the actual contemporaneous field measurements. Many scientists are of the opinion that since there is no plausible biological basis, it is inconceivable that power frequency EMF at field strengths typically encountered in and around residences in the proximity of high voltage transmission lines could pose an increased risk of cancer in humans.

To what extent high voltage transmission lines incrementally contribute to daily exposure of EMF is still an enigma. This is because exposure to EMF is unavoidable due to ubiquitous sources other than high voltage transmission lines, such as wall wiring, lighting fixtures, distribution lines, substations, and from the use of a vast array of electrical appliances, such as televisions, clocks, computers, ovens, ranges, toasters, blenders, hair-dryers, irons, shavers, blankets, power tools, *etc*. Admittedly, some of these appliances are used for short intervals, yet cumulative daily exposure to EMF from these devices is most likely to exceed that from high voltage transmission lines.

The preponderance of evidence in the scientific literature available to date for causation of cancer or any other deleterious effects in humans from exposure to EMF from nearby high voltage transmission lines is neither convincing nor consistent. The studies published in the literature lack clear demonstration of a significant causal relationship and a definitive dose-response gradient. There is no widely accepted biological mechanism or a theory of how power frequency EMF could cause a disease. There are no specific clinical signs or symptoms for disease(s) possibly associated with exposure to low frequency EMF. To date, there are no specific clinical confirmatory tests or biomarkers that could assess past exposure to EMF or potentially help in either confirming or excluding diagnosis of a disease, if any, linked to either electric or magnetic fields or both. Evidence from the laboratory studies has thus far failed to show that exposure to EMF causes cancer in experimental animals. Experiments have also failed to show how EMF could initiate or promote the growth of cancer. Both *in vivo* and *in vitro* experimental studies therefore, do not lend support to an implied association between exposure to EMF and cancer.

Epidemiologic studies examining the possible association between EMF and cancer have some inherent strengths and weaknesses. In order to detect an association between a given risk factor and disease, an epidemiologic study must control for other potential risk factors that may be confounding this association. Even when all potential risk factors are known and controlled to the maximum extent possible, it is frequently impossible to rule out confounding when the strength of an association observed between the risk factor of interest and disease is weak. In reality, it is seldom possible to control for all other potential risk factors, because for many diseases, like various forms of cancer, those other risk factors are unknown. Some epidemiologic studies have found that exposure to EMF may confer a two- to three-fold increased risk of certain cancers. This is a fairly small increase when compared to the association between cigarette smoking and cancer, where the risk is increased by ten-fold or greater. Furthermore, exposure to EMF is universal and unavoidable. Thus, it is not possible to find a control group of individuals who would be unexposed; only populations

with relatively greater or lesser exposure can be compared. Also, past exposure can only be estimated based on wiring configuration. There is no biological test to assess past exposure and current environmental measurements may be misleading. The assumption that the exposed group would have had a higher exposure to electromagnetic fields than the rest of the population may not be true and therefore, may skew the interpretation of the results of epidemiologic studies.

Although epidemiologic studies may fail to find an association between a given risk factor and disease, it is practically impossible for any epidemiologic study to rule out the possibility of a weak association. This is because the power of a study to confirm a negative association hinges on the prevalence of the disease of interest and the size of the study population. Because of the rarity of most tumors, any competent epidemiologic study that attempts to rule out very small associations between EMF and one type of cancer would have to include an exceedingly large population. Such a study would almost certainly be cost-prohibitive.

Scientific proof of a cause and effect relationship cannot be readily inferred from a single epidemiologic study. Causality is established using multiple criteria, only one of which is epidemiologic association. Other important factors in confirming a cause and effect relationship include strength of association, consistency and specificity of observations, appropriate temporal relationship, dose-response relationship, biological plausibility, and experimental verification. None of these factors by itself is sufficient to prove or disprove that an observed association represents a true cause and effect relationship. In the case of EMF, these tests for causality have not been satisfied for the implicit deleterious effects.

Laboratory experiments conducted on cells, tissues, and whole animals have shown that under certain conditions, exposure to EMF can produce changes in behavior and nervous system activity, and alterations in biological rhythms and the production of certain hormones. Biological changes such as these are not necessarily physiologically significant. Hence, it cannot be determined that these biological effects translate into adverse human health effects. The observed effects depend upon various factors, including field strength, frequency, duration of exposure, variability of exposure, rate of change in intensity, and interaction with the Earth's magnetic field. Unlike ionizing radiation, power frequency EMF do not appear to cause direct damage to DNA or other genetic material. Thus, it is believed that exposure to EMF could not, by itself, initiate cancer. However, some scientists have postulated that electric and/or magnetic fields may potentially serve as cancer promoters (an agent which facilitates the growth of a cancer which has already been initiated). These hypotheses are now being tested by researchers.

The Virginia Department of Health and the State Corporation Commission will continue to monitor the ongoing studies on the subject, and will inform the members of the General Assembly should evidence emerge establishing a clear link between adverse human health effects and EMF exposure.

Introduction

The Virginia General Assembly in its 1984 Session, pursuant to Senate Joint Resolution No. 26, resolved to establish a joint subcommittee to study the adequacy of the State Corporation Commission (SCC) oversight, the health and safety rules and regulations, and the statutes in the *Code of Virginia* in protecting the citizens of the Commonwealth when high voltage electrical transmission lines are constructed and maintained. The joint subcommittee held its first meeting on June 8, 1984, during which the Virginia Department of Health (VDH) was asked to review the human health effects of high voltage transmission lines. A report, "Health Effects of High Voltage Transmission Lines," dated August 15, 1984, was formally submitted to the members of the joint subcommittee during a meeting held on November 16, 1984.

Pursuant to Senate Joint Resolution No. 126 of the 1985 Session of the General Assembly (Appendix A), the SCC and VDH were requested to monitor the ongoing research on the health and safety effects of high voltage transmission lines. Further, the VDH, after consultation with the SCC, was requested to report its findings annually to the General Assembly.

The 1993 Session of the General Assembly adopted Senate Joint Resolution No. 278 (Appendix B), requesting that the VDH and the SCC continue to monitor relevant ongoing research as described in Senate Joint Resolution No. 126 of the 1985 Session and to submit annual reports thereon. Senate Joint Resolution No. 278 of the 1993 Session also requested that as part of the foregoing activity, the VDH and the SCC monitor and, if feasible, participate in the study of electric and magnetic fields pursuant to the Federal Energy Policy Act of 1992.

This thirteenth annual update of the 1984 report supplements information contained in the preceding reports. Previous reports in the series are listed in Appendix C. An overview of the literature that became available in 1996-1997 is presented in this report. Pursuant to Senate Joint Resolution No. 126 of the 1985 Session and Senate Joint Resolution No. 278 of the 1993 Session, this thirteenth annual report on monitoring of ongoing research on the human health effects of high voltage transmission lines is submitted to the members of the 1998 Virginia General Assembly.

Background

Electric and magnetic fields, often referred to as electromagnetic fields (EMF), occur both naturally and as a result of generation, delivery, and use of electric power. In our society, where the use of electric power is pervasive, exposure to EMF is common from the vast array of electrical appliances and equipment, building wiring, distribution lines, and transmission lines.

EMF are fields of force and are created by electric voltage and current. They occur around electrical devices or whenever power lines are energized. Electric fields are due to voltage so they are present in electrical appliances and cords whenever the electric cord to an appliance is plugged into an outlet (even if the appliance is turned off). The strength of the electric field is typically measured in volts per meter (V/m) or in kilovolts per meter (kV/m). Electric fields are weakened by objects like trees, buildings, and vehicles. Burying power lines can eliminate human exposure to electric fields from this source.

Magnetic fields result from the motion of the electric charge or current, such as when there is current flowing through a power line or when an appliance is plugged in and turned on. Appliances which are plugged in but not turned on do not produce magnetic fields. Magnetic fields are typically measured in tesla (T), or more commonly, in gauss (G) and milligauss (mG). One tesla equals 10,000 gauss and one gauss equals 1,000 milligauss. The strength of EMF decreases significantly with increasing distance from the source (1).

The Earth's natural electric field is essentially static (non-alternating) and is about 130 V/m. The Earth's magnetic field is also static and is about 0.5 G or 500 mG. In the United States, the electric power system uses alternating current (AC) that alternates back and forth (frequency) 60 times each second and is called 60-Hertz (60-Hz; cycles per second) power. In Europe and many other parts of the world, the frequency of electric power is 50-Hz.

There are basically three stages in generating electricity, or power, and moving the electricity from the electric stations to the end user. First, electricity is generated at an electrical generating station at about 20,000 volts or 20 kilovolts (kV). The power is then passed through a transformer which increases the voltage so that the power can be transported with minimum losses. In the second stage, electricity is transported over high voltage transmission lines ranging from 69 to 765 kV. Transmission lines connect to substations where the voltage is reduced and power is transferred to lower-voltage distribution lines. In the third stage, distribution lines deliver power locally to individual users. The distribution system is

composed of two voltage levels. One is a "primary" circuit (2 to 59 kV) that delivers power from a substation to a distribution transformer. From there the power flows through a "secondary" circuit to an end user. The "secondary" circuit voltage is low enough (120 to 240 volts) to operate household electrical appliances, lights, etc. The amount of power that a line transmits is the product of its voltage and current. Power systems are designed to hold voltages relatively constant, while currents increase and decrease depending on the power demand. For a given voltage, the electric field remains relatively constant over time, but the magnetic field increases or decreases depending upon power demand (2).

The EMF from power lines and appliances are of extremely low frequency (ELF) and low energy. They are non-ionizing and are markedly different in frequency from ionizing radiation such as X-rays and gamma rays. As a comparison, transmission lines have a low frequency of 60-Hz while television transmitters have higher frequencies in the 55-890 million Hz (MHZ) range. Microwaves have even higher frequencies, 1,000 MHZ and above. Ionizing radiation such as X-rays and gamma rays has frequencies above 10^{15} Hz. The energy from higher-frequency fields is absorbed more readily by biological material. Microwaves can be absorbed by water in body tissues and cause heating which can be harmful, depending upon the degree of heating that occurs. X-rays have so much energy that they can ionize (form charged particles) and break up molecules of genetic material (DNA) and nongenetic material, leading to cell death or mutation. In contrast, extremely low frequency EMF do not have enough energy to heat body tissues or cause ionization (3).

Currently, in the United States there are more than 300,000 miles of AC power transmission lines ranging from 115 to 765 kV. In Virginia, the highest voltage on transmission lines is 765 kV. A typical home in the United States has a background magnetic field level (away from any appliances) that ranges from 0.5 mG to 4 mG, with an average level of 0.9 mG. Magnetic fields very close to most electrical appliances are often stronger than the fields directly beneath transmission lines. However, appliance fields decrease in strength with distance more quickly than do transmission line fields.

The strength of an electric field is proportional to the voltage of the source. Thus, the electric fields beneath high voltage transmission lines far exceed those below the lower voltage distribution lines. The magnetic field strength, by contrast, is proportional to the current in the lines, so that a low voltage distribution line with a high current load may produce a magnetic field that is as high as those produced by some high voltage transmission lines. In fact, electric distribution systems account for a far higher proportion of the population's exposure to magnetic fields than the larger and more obvious high voltage transmission lines (4).

Over the past three decades, both public controversy and scientific uncertainty have surrounded the subject of potential adverse human health effects from exposure to power frequency EMF. The first studies of possible health effects of EMF exposure in an occupational environment were reported from the former Union of Soviet Socialist Republics (USSR) in the mid-1960s. Several subjective complaints, involving the cardiovascular, digestive, and central nervous systems, were reported by electric switchyard workers. Subsequent studies of electric utility linemen in the United States failed to observe the same adverse health effects reported by their counterparts in the former USSR. Since that time, enormous strides have been taken to explore the nature of any association between residential and occupational exposures to EMF and deleterious health effects.

Recently, there has been a growing concern about the possible carcinogenic effects of EMF associated with such exposures. Since 1979, several epidemiologic studies have explored the association between exposure to EMF and increased risk of leukemia in children. Other epidemiologic studies have also examined increased incidence of leukemia and brain cancer among adults, especially with respect to occupational EMF exposure. In earlier studies there was an implicit assumption that the relevant risk factor was exposure to electric fields. However, virtually all recent epidemiologic studies of cancer have focused on magnetic field exposures as the possible etiologic determinant.

An Overview of Literature on the Health Effects of High Voltage Transmission Lines, 1996 - 1997

Since the submission of the last report, entitled "Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Twelfth Annual Report)," dated March 20, 1997, several articles, reports, and reviews have become available in the literature on this subject. The following is an overview of the publications reviewed for this report. Conclusions from the various publications are either extracted verbatim or represent the views of the investigators and authors of the publications.

The National Academy of Sciences (NAS) Review

In 1991, the U.S. Congress asked that the National Academy of Sciences (NAS) review the research literature on the effects from exposure to low-strength, low- frequency EMF and determine whether the scientific basis was sufficient to assess health risks from such exposures. In response, the National Research Council of the NAS convened the Committee on the Possible Effects of Electromagnetic Fields on Biological Systems. The committee was asked to review and evaluate the existing scientific information on the possible effects of EMF exposure on the incidence of cancer, on reproduction and developmental abnormalities, and on neurobiologic response. The NAS (5) recently published the committee's 356-page review encompassing over 15 years of EMF research. Based on a comprehensive evaluation of published studies relating to the effects of power frequency electric and magnetic fields on cells, tissues, and organisms (including humans), the conclusion of the committee is that the current body of evidence does not show that exposure to these fields presents a human health hazard. Specifically, no conclusive and consistent evidence shows that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects.

The committee reviewed residential exposure levels to electric and magnetic fields, evaluated the available epidemiologic studies, and examined laboratory investigations that used cells, isolated tissues, and animals. At exposure levels well above those normally encountered in residences, electric and magnetic fields can produce biologic effects (promotion of bone healing is an example), but these effects do not provide a consistent picture of a relationship between the biologic effects of these fields and health hazards. An association between residential wiring configurations and childhood leukemia persists in multiple studies, although the causative factor responsible for that statistical association has not been identified. No evidence links contemporary measurements of magnetic-field levels to child-

hood leukemia. The NAS review findings relevant to epidemiologic studies available in the literature are as follows:

- Living in homes classified as being in the high wire-code category is associated with about 1.5-fold excess of childhood leukemia, a rare disease.

- Magnetic fields measured in the home after diagnosis of disease in a resident have not been found to be associated with an excess incidence of childhood leukemia or other cancers.

- Studies have not identified the factors that explain the association between wire codes and childhood leukemia.

- In the aggregate, epidemiologic evidence does not support possible associations of magnetic fields with adult cancers, pregnancy outcome, neurobehavioral disorders, and childhood cancers other than leukemia.

The NAS committee also evaluated several published studies on experiments in animals and concluded the following.

- There is no convincing evidence that exposure to 60-Hz electric and magnetic fields causes cancer in animals.

- There is no evidence of any adverse effects on reproduction or development in animals, particularly mammals, from exposure to power-frequency 50- or 60-Hz electric and magnetic fields.

- There is convincing evidence of behavioral response to electric and magnetic fields that are considerably larger than those encountered in the residential environment; however, adverse neurobehavioral effects of even strong fields have not been demonstrated.

- Neuroendocrine changes associated with magnetic-field exposure have been reported; however, alterations in neuroendocrine function by magnetic-field exposures have not been shown to cause adverse health effects.

- There is convincing evidence that low-frequency pulsed magnetic fields greater than 5 G are associated with bone-healing responses in animals.

The Bioelectromagnetics Society's Statement

The Bioelectromagnetic Society (BEMS) is a scientific society which was established in 1979 to promote the study of the interaction of electromagnetic energy with biological systems. The BEMS has recently issued a position statement (6) regarding scientific research on biological effects of EMF. Excerpts from the statement are as follows:

> The health questions associated with exposure of individuals to extremely low frequency (ELF) electric and magnetic fields have been driven largely by cancer epidemiological studies. The first such study was reported in 1979 and a number of studies have appeared since with variable results. Strong criticism of these epidemiological studies has been due primarily to this variability of results as well as the incomplete nature of laboratory data to support the specific cancer findings. Additional difficulties in the evaluation of the epidemiological data are that the apparent increases in cancer are relatively low, and that there is at present no proven mechanistic explanation to support the epidemiological findings. The answers to these exposure and health questions can only be clarified through a well coordinated and funded research program.
>
> Both public concern and the potential cost of engineering mitigation are considerable. A large portion of the population of industrialized nations is exposed and thus potentially at risk. However, it is yet to be determined whether there is cause for concern or what the appropriate mitigation, if any, should be. Whether adverse effects are (1) real and significant, (2) real but of minor importance, or (3) nonexistent, must be determined by current and future research to allay public fears and to provide to industry a basis for appropriate response or action.

European Commission's EMF Health Effects Review

A European Commission advisory panel has issued conclusions and recommendations (7) on EMF health effects research direction and standard setting.

> Some epidemiological reports present data indicative of an increase in cancer among children, adults and occupational groups. The current theoreti-

> cal basis for the interaction of 50/60-Hz fields with living systems cannot explain such associations.... The overall conclusions of different expert groups are similar, viz. although the results of more recent studies reflect some improvements in methodology, the data do not provide convincing evidence that electromagnetic fields and radiation are carcinogenic.
>
> There is no persuasive evidence that ELF electromagnetic fields are able to influence any of the accepted stages in carcinogenesis. Effects on initiation are extremely unlikely suggesting that if there is an effect it will be at the level of promotion or progression....

The Maryland Department of Natural Resources Status Report

The Maryland Department of Natural Resources, Power Plant Research Program issued its seventh report entitled "Status Report on Investigations of Potential Human Health Effects Associated with Power Frequency Electric and Magnetic Fields" (8). The report reviewed the recently published literature on health effects of EMF. The report's conclusions are as follows:

> The possibility that magnetic fields associated with electric power transmission may cause some cases of childhood cancer, some kinds of adult cancer, and several other diseases cannot be dismissed, but the lack of consistency between published studies and the lack of a plausible biological explanation for such an association means that a causal relationship has not been established. Although studies continue to provide evidence of biological effects, the health implications of exposure to EMF continue to be unclear. In addition, the biophysical or biological mechanisms that would explain how EMF interacts with living organisms to produce these effects are not understood. More scientific research is needed to learn which, if any, aspects of exposure are relevant to human health risks.

The National Cancer Institute Study of Leukemia in Children

Linet *et al.* (9) published the results of a recent study of residential exposure to magnetic fields generated by nearby power lines. This is a very large residential study sponsored by the National Cancer Institute and comprised 638 children under 15 years of age from nine states and who were diagnosed with acute lymphoblastic leukemia. The control group consisted of 620 children.

Magnetic fields were measured for 24 hours in each child's bedroom and for 30 seconds in three or four other rooms and outside the front door. A computer algorithm assigned wire-code categories, based on the distance and configuration of nearby power lines, to the subjects' main residences, and to those where the family had lived during the mother's pregnancy with the subject.

The results of the study did not show an association between the risk of acute lymphoblastic leukemia and exposure to residential magnetic fields at or above 2.0 mG as compared with exposures at less than 0.65 mG. The risk of leukemia was not increased among children whose main residences were in the highest wire-code category (odds ratio 0.88; 95% confidence interval 0.48-1.63). Furthermore, the risk of leukemia was not significantly associated with either residential magnetic field levels or the wire codes of the homes mothers resided in when pregnant with the subjects.

Residential Study in Finland

Verkasalo *et al.* (10) conducted a nationwide cohort study in Finland to investigate the risk of cancer among adults living close to high voltage power lines. The study included 383,700 people who lived during 1970-89 within 1500 feet of overhead power lines of 110-400 kV. The average magnetic field exposure in residences was calculated to be greater than 0.1 mG. In the calculation of magnetic field strengths, variables such as current, type of power lines, and the shortest distance from the power line to the central point of the residence were taken into account. These data cover about 11,000 miles or 90% of the total length of respective power lines in Finland. Study subjects and incidence of cancer were identified from Nationwide Central Population Register, Population Census 1970, and Finnish Cancer Registry.

For the overall cohort, no excess cancer risk was observed compared with the general Finnish population. Altogether, 8,415 cases of cancer were observed (standardized incidence ratio 0.98; 95% confidence interval 0.96-1.00). When the data were analyzed by sex, statistically significant excesses were observed in multiple myeloma in men (incidence rate ratio 1.22; 95% confidence interval 1.00-1.49) and in colon cancer in women (incidence rate ratio 1.16; 95% of confidence interval 1.03-1.29). However, these excesses were considered by the authors of the study to be due to chance. The authors concluded that typical residential magnetic fields generated by high voltage power lines do not seem to be related to the risk of overall cancer in adults. The previously suggested associations between extremely low frequency magnetic fields and tumors of the nervous system, lymphoma, and leukemia in adults and breast cancer in women were not confirmed.

Residential Study of Adult Cancer in Taiwan

A case-control study was conducted in northern Taiwan by Li *et al.* (11) to evaluate the risks of adult leukemia, brain tumors, and female breast cancers in relation to residential exposure to magnetic fields from nearby transmission lines. Cases and controls were identified from the National Cancer Registry of Taiwan. Cases were persons with newly diagnosed cancers reported to the cancer registry between 1987 and 1992 and who were 15 years of age or older. Controls were cancer patients with a diagnosis other than cancers of the hematopoietic and reticuloendothelial systems, male breast, skin, ovary, fallopian tube, and prostate gland. Controls were matched on date of birth, sex, and date of diagnosis. All study subjects were residents of one of the four administrative areas of Taipei City, Keelung, Taiepi County, and Taoyuan at the time of diagnosis. The study comprised of 870 cases of leukemia, 577 cases of brain tumors, and 1,980 cases of female breast cancer. Distance from the nearest transmission line to the residence of study subjects was measured by the maps provided by Taiwan Power Company. Magnetic fields in the residences of the study subjects at the time of diagnosis were estimated using annual average and maximum loading data for the transmission lines. Spot magnetic field measurements were made in 407 homes to verify the calculated field levels.

Relative risk estimates or odds ratios were calculated for distance of residence from the transmission line: 0-49 meters and 50-99 meters relative to a >99 meters reference category. Odds ratios were also calculated for magnetic fields: 1-2 mG and >2 mG relative to a <1 mG reference category. The odds ratio for leukemia among those who lived at a distance of 0-49 meters from the transmission line was 2.0 (95% confidence interval 1.4-2.9). The odds ratio for those who lived at a distance of 50-99 meters from the transmission line was 1.5 (95% confidence interval 1.1-2.3). The odds ratio for leukemia among those exposed to magnetic fields at 1-2 mG was 1.3 (95% confidence interval 0.8-1.9). The odds ratio for leukemia among those exposed to magnetic field at >2 mG was 1.4 (95% confidence interval 1.0-1.9). For brain tumors and female breast cancers, the odds ratios were close to unity and were not statistically significant.

This study was based on the residence of the subjects at the time of diagnosis. It was not possible to obtain each subject's residential history, and therefore no cumulative exposure index could be calculated. Also, the authors of the study were unable to adjust for known factors for leukemia, brain tumors, or female breast cancers.

Norwegian Childhood Cancer Study

Tynes and Haldorsen (12) conducted a population-based nested case-control study in Norway to evaluate the risk of childhood cancer in relation to exposure to EMF from high voltage transmission lines. The study population comprised children aged 0-14 years who had lived in a census ward crossed by a high voltage transmission line during at least one of the years 1960, 1970, 1980, 1985, 1987, or 1989. A census ward is an area within a municipality, the population of which may range from less than a hundred in rural areas to over a thousand in some urban areas. The cases were diagnosed from 1965-1989 and were matched to controls by year of birth, sex, and municipality. Exposure to electric and magnetic fields was calculated by means of power line characteristics and distance of residence from the power line. A total of 500 cases and 2,004 controls were included in the study. No association was found between exposure to time-weighted average exposure to magnetic fields and cancer at all sites, brain tumors, lymphoma, or leukemia. Cancer at other sites showed elevated odds ratios in the two highest exposure categories in some, but not all, measures of exposure. The study provides little support for an association between childhood exposure to magnetic fields and cancer and no support for an association between leukemia and such exposure.

Brain Tumor Risk in Children and Use of Electric Blankets

The possible relation between the occurrence of brain tumors in children and exposure to electric blankets or electrically heated water beds was investigated by Preston-Martin *et al.* (13) in a population-based case-control study conducted on the West Coast of the United States. Cases were children 19 years of age or younger and were diagnosed between 1984 and 1991. Subjects were from three regions of the western United States: Los Angeles County in Southern California; five counties in Northern California that comprise the San Francisco-Oakland metropolitan area; and 13 counties in western Washington State, including the Seattle-Puget Sound metropolitan area. The study comprised 540 cases and 801 control children. The risk of brain tumor occurrence from *in utero* exposure to either electric blankets or electrically heated water beds was not found to be elevated. Brain cancer risk did not vary by use in any trimester of pregnancy, and children with mothers who reported use throughout their pregnancy had no increased risk. Risk did not vary significantly by age, sex, race, socioeconomic status, or histologic category for either *in utero* exposure or child's exposure.

Canadian Occupational Study of Electric Utility Workers

In a nested control study, Miller *et al.* (14) evaluated association of cancer risk with electric field exposure. The study included 1,484 cancer cases and 2,179 matched controls

from a cohort of 31,543 Ontario Hydro male employees. Active workers were followed from January 1973 through December 1988. Retirees were followed from January 1970 through December 1988. The period of observation for the detection of cases of cancer began after one year of full employment and ceased with the death of the worker or on December 31, 1988, whichever was earlier. Exposures to electric and magnetic fields and to potential occupational confounders were estimated through job matrices. The odds ratio for all leukemia cases was 4.45 (95% confidence interval 1.01-19.7) for cumulative exposure to electric fields at or above 345 volts per meter-year. Odds ratios for leukemia subtypes, viz. acute myeloid leukemia, acute nonlymphoid leukemia, and chronic lymphoid leukemia, were also elevated, but were not statistically significant. When the data were analyzed with respect to magnetic fields exposure, the odds ratios for leukemia, brain cancer or lung cancer were not statistically significant.

French Occupational Study of Electric Utility Workers

A case-control study (15) was conducted to determine whether occupational exposure to electric fields was associated with cancer among electric utility workers in France. The study nested within a cohort of 170,000 workers employed at Électricité de France-Gaz de France (EDF) between 1978 and 1989. All incident cases of cancer and benign tumor of the brain diagnosed in 1978-1989 among workers before the age of retirement were included. Four randomly selected controls were individually matched to each case by year of birth. The exposure to electric field was assessed from measurements collected in 850 EDF workers for a full work week.

The analysis by site of tumor did not show any increased risk for leukemia (72 cases). An excess risk (69 cases) was observed for all brain tumors (odds ratio 3.08; 95% confidence interval 1.08-8.74) for electric fields exposure above the 90th percentile (^{3} 387 volts per meter-year). However, electric fields could not be linked with any particular form of brain tumor, benign or malignant. An unexpected association was also observed for colon cancer, possibly related to confounding from other occupational risk factors. The authors concluded that these results tend to confirm the hypothesis that occupational exposure to 50-Hz electric fields increases brain tumor risk. The authors also suggested that electric fields should be taken into account in future analyses of epidemiologic data for testing the associations between extremely low frequency fields and cancer.

British Electrical Workers Studies

A British study (16) investigating brain cancer mortality among electric utility workers did not support the hypothesis that the risk of brain cancer is associated with exposure to magnetic fields. This study was based on a large cohort of 84,018 men and women who had

worked for at least six months for a British electric utility company between 1972 and 1984. Information on vital status was obtained from the United Kingdom Department of Social Security, with death certificates from the Office of Population, Census and Surveys. Exposure assessment was based on a personal exposure survey of 258 volunteer electric utility workers. The volunteers worked in various occupations.

A total of 10,010 cohort members were identified as having died by December 1991. Of these, 112 were primary brain cancer cases. The analysis of data did not show any statistically significant increase in relative risk for brain cancer associated with exposure to magnetic fields among the British electric utility workers. The risk of mortality from brain cancer for subjects with an estimated cumulative exposure to magnetic fields of 54-134 mG-year was 1.04 (95% confidence interval 0.60-1.80) as compared with subjects with lower exposures of 0-53 mG-year. The corresponding relative risk in subjects with higher exposures (>135 mG-year) was 0.95 (95% confidence interval 0.54-1.69). There was no indication of a positive trend for cumulative exposure and risk of mortality from brain cancer either when the analysis used exposure assessments based on geometric means or when the analysis was restricted to exposures received within five years of the case diagnosis.

Another large scale study of English workers with presumed occupational exposure to EMF was conducted by Fear *et al.* (17). The investigators assessed cancer incidence using data for 371,890 cancers registered in England between 1981 and 1987, of which 7,981 were in electrical and electronic industries. The proportional registration ratio (PRR) was used as the measure of association between cancer site and occupation. PRRs were calculated with and without most common cancers, with adjustment for age, social class, cancer registry of origin, and sex. PRR for leukemia was 124 (95% confidence interval 109-142) and for brain cancer it was 118 (95% confidence interval 103-136). A significantly increased risk was also observed for pleural cancer, PRR 201 (95% of confidence interval 167-241) based on 115 cases. However, the authors of the study caution, “The extent to which workplace exposures to extremely low frequency electromagnetic fields explains the excesses seen here for leukemia and brain cancer requires further study.”

It should be noted that PPR analysis allows only limited conclusions. Such studies are typically used for hypothesis generation, not hypothesis testing. PRRs do not directly reveal or compare the actual risks from a specific cause. They only compare the proportional incidence of a cause to the expected proportion, based on the experience of a larger, more diversified group.

Occupational Exposure to EMF and Risk of Breast Cancer in Women

A population-based case-control study was conducted by Coogan *et al.* (18) to compare the incidence of breast cancer among women whose occupational exposure to magnetic fields was higher than those without such exposure. Breast cancer cases were identified from Maine, Wisconsin, Massachusetts, and New Hampshire who were 74 years of age or younger, and who were reported to the state cancer registry between April 1988 and December 1991. Controls were randomly selected from lists of licensed drivers and Medicare beneficiaries. Information on usual occupation and breast cancer risk factors was obtained by telephone interview. The study included 6,851 cases and 9,475 controls. Cases and controls were assigned to four exposure categories, viz. background (presumed not occupationally exposed to EMF), low exposure, medium exposure, and high exposure, based on their occupations. There was a modest increase in risk for women with potential for high exposure, odds ratio 1.43 (95% confidence interval 0.99-2.09). There was no increase in risk for women with potential for medium exposure, odds ratio 1.09 (95% confidence interval 0.83-1.42) or low exposure, odds ratio 1.02 (95% confidence interval 0.91-1.15). The risk among premenopausal women in the highest exposure category was higher, odds ratio 1.98 (95% confidence interval 1.04-3.78) than for postmenopausal women, odds ratio 1.33 (95% confidence interval 0.82-2.17).

A major limitation of this study was misclassification of exposure. Exposure was based on the subjects response to a question about most representative occupation. Although workers in electrical occupations have higher exposures to magnetic fields than non-electrical workers, there is considerable variation in exposure between occupations included in the same aggregate exposure category, and also within the same occupations.

Occupational Exposure to EMF and Risk of Alzheimer's Disease

Sobel *et al.* (19) conducted a case-control study of the possible association of occupations with likely exposure to EMF and Alzheimer's disease with patients from the Alzheimer Disease Treatment and Diagnostic Center, Rancho Los Amigos Medical Center, Downey, California. Cases were patients with a diagnosis of definite or probable Alzheimer's disease (86 male, 240 female). Controls were patients who were cognitively impaired or demented (76 male, 76 female). The study was limited to patients who were at least age 65 at the time of their first examination. The patients primary occupation throughout life was used as the basis for EMF exposure assessment. Each occupation was assigned a high, medium, or low exposure category. Occupations presumed to have average exposures above 10 mG, or presumed intermittent exposure above 100 mG, were assigned as high. Occupations with 2-10 mG average, or above 10 mG intermittent exposures were assigned as medium. All other occupations were in the low exposure category. No actual measurements of EMF were

made. No information was collected on the length of employment in specific occupations. The odds ratio for both sexes combined was adjusted for sex, education, and age at onset. The odds ratio for males was adjusted only for age at onset, and the odds ratio for females was adjusted for both education, and age at onset. The adjusted odds ratio for both sexes was 3.93 (95% confidence interval 1.5-10.6). For males the adjusted odds ratio was 4.9 (95% confidence interval 1.3-7.9), and for females the adjusted odds ratio was 3.4 (95% confidence interval 0.8-16).

Energy Policy Act of 1992

A federally coordinated EMF Research and Public Information Dissemination (RAPID) Program was established by the Energy Policy Act of 1992. Section 2118 of the Act directs the U.S. Department of Energy (DOE) to establish a comprehensive program to:

- determine whether or not exposure to electric and magnetic fields produced by generation, transmission, and use of electric energy affects human health;

- carry out research, development, and demonstration with respect to technologies to mitigate any adverse human health effects; and

- provide for dissemination of information on possible human health effects, the types and extent of human exposure to EMF, technologies to measure and characterize fields, and methods to assess and manage EMF exposure.

DOE is responsible for the overall administration of the 5-year, $65 million EMF RAPID Program and directs research on exposure assessment and field management techniques. The National Institute of Environmental Health Sciences (NIEHS) directs the risk assessment and health effects research. The public information component of the program is the responsibility of both DOE and NIEHS. The program is jointly funded by both Federal and non-Federal sources. Non-Federal source contributions account for at least 50% of the total funding (20).

The Act also establishes two committees and their responsibilities to ensure broad representation of expertise and interest in the EMF issue. An Interagency Committee representing nine Federal agencies is responsible for the following: developing the program agenda; establishing guidelines for interagency coordination; and monitoring, evaluating, and reporting program results. The Interagency Committee includes:

- Department of Energy
- National Institute of Environmental Health Sciences
- Environmental Protection Agency
- Department of Defense
- Occupational Safety and Health Administration (Department of Labor)
- National Institute of Standards and Technology (Department of Commerce)
- Department of Transportation
- Rural Electrification Administration (Department of Agriculture)
- Federal Energy Regulatory Commission

The Interagency Committee, established by the President of the United States, must also prepare two reports to the Congress: an interim report in 1995 and a final report in 1997.

The RAPID Program also receives guidance from the National EMF Advisory Committee (NEMFAC), whose members are drawn from representative constituencies including public interest groups, organized labor, state governments, academia, and industry. The Advisory Committee also provides recommendations to the Interagency Committee on several tasks.

The RAPID Program has the central goal of determining if electric and magnetic fields associated with the generation, transmission, and use of electrical energy pose a risk to human health. The fact that 20 years of research have not answered that question is clear evidence that health effects of EMF are not obvious and that risk relationships, if risk is identified, are not simple. Because epidemiologic studies have raised concerns regarding the connection between certain serious human health effects and exposure to electromagnetic fields, the program adopts the hypothesis that exposure to electric or magnetic fields under some conditions may lead to unacceptable risk to human health. The focus of the program is not only to test, as far as possible within the statutory time limits, that hypothesis for those serious health effects already identified, but to identify as far as possible the special conditions that lead to elevated risk and to recommend measures to manage risk. The RAPID Program complements other Federal and non-Federal EMF research, and the results of these other programs will be considered in light of the new data obtained from the RAPID Program (20).

An important feature of the RAPID Program that distinguishes it from previous programs is its focus on a risk assessment framework for decision making. This includes the specific task of developing a detailed risk assessment model for potential human health effects of electric and magnetic fields, as well as adopting an overall risk assessment approach for all activities funded. The risk assessment approach during the early phases of the program will be useful in reviewing the evidence of existing research to determine gaps and areas where resources should be focused. In the later phases of the program, risk assessment research will form the basis for decision-makers' interpretation of the health effects research and suggest directions for assessing the nature and extent of any risk. Further, risk assessment research is expected to assist program managers with systematic identification of key issues related to potential health effects. Consequently, it will be an invaluable tool in directing the communication component of the program.

The risk assessment framework is an important cornerstone of the entire RAPID research program. The framework provides a context for making funding decisions and should not be confused with the formal risk assessment model, which will be independently developed for the program. Since research funded under the RAPID Program must be oriented toward testing the overall hypothesis, some methodology must be employed to ensure that all research incrementally addresses the hypothesis in the context of the specific human endpoints selected. Thus, the hazard identification process must be employed to determine what additional information is needed to test the hypothesis. This approach will ensure that all research is policy focused. Specific steps for implementing the risk assessment framework will be developed by NIEHS.

Essential to the RAPID Program strategy is a continual application of the risk assessment approach. Evaluation of research conducted through the program, and independent of the program, will be ongoing and will be used to refine program activities by redirecting, expanding or concentrating the areas of research. Such refinements should result in narrowing the focus to those health effects and areas of research that will maximize the chance of being able to answer the statutory questions within the program time frame (20).

Conclusion

Over the past several years, hundreds of epidemiologic studies and laboratory experiments, both *in vivo* and *in vitro,* have been conducted attempting to determine the specific nature and magnitude of the potential adverse effects on human health attributable to EMF exposure from high voltage transmission lines. The epidemiologic studies have most extensively investigated the occurrence of leukemia, especially childhood leukemia, and brain tumors among residents living near high voltage transmission lines and among workers occupationally exposed to EMF.

Based on the review and analysis of the available scientific literature to date, the preponderance of evidence for causation of cancer or any other deleterious effects in humans from exposure to EMF from nearby high voltage transmission lines is neither convincing nor consistent. The studies published in the literature lack clear demonstration of a significant causal relationship or a definitive dose-response gradient. The empirical relative risk implied in some of the epidemiological studies is fairly small in magnitude, often statistically insignificant, and, albeit suggestive, does not necessarily prove a causal correlation. A two- to three-fold increase in relative risk of certain cancers observed in some studies is within the range where experimental bias or confounding factors cannot be completely ruled out. There is no widely accepted biological mechanism or a theory of how power frequency EMF could cause a disease. There are no specific clinical signs or symptoms for disease(s) possibly associated with exposure to low frequency EMF. To date, there are no specific clinical confirmatory tests or biomarkers that could assess past exposure to EMF or potentially help in either confirming or excluding diagnosis of a disease, if any, linked to either electric or magnetic fields or both. Evidence from the laboratory studies has thus far failed to confirm that exposure to EMF causes cancer in experimental animals. Laboratory experiments have also failed to show how EMF could initiate or promote the growth of cancer. The results of both *in vivo* and *in vitro* experimental studies conducted so far do not lend support to an association between exposure to EMF and cancer. Furthermore, scientific proof of a causal association is established using multiple criteria, only one of which is epidemiologic association. Other important criteria in confirming causality include strength of association, consistency and specificity of observations, appropriate temporal relationship, dose-response relationship, biological plausibility, and experimental verification. In the case of EMF, these criteria for causality have not been satisfied for the implicit adverse effects.

These conclusions are in concurrence with and supported by numerous exhaustive reviews and evaluations of the scientific literature by several well-recognized scientific bodies, commissions, and expert panels worldwide. Recent literature reviews, evaluations,

and position statements include those published by the National Academy of Sciences, the Oak Ridge Associated Universities Panel, the American Medical Association, the American Cancer Society, the American Physical Society, several states' Public Utilities Commissions, the European Commission, the United Kingdom's National Radiological Protection Board, the United Kingdom's Institution of Electrical Engineers, the Australian Ministry for Health, the French National Academy of Medicine, and the French National Institute of Health and Medical Research.

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Appendix A

Senate Joint Resolution No. 126

Requesting the State Corporation Commission and the Department of Health to monitor ongoing research on the health and safety effects of high voltage transmission lines.

Agreed to by the Senate, January 30, 1985
Agreed to by the House of Delegates, February 14, 1985

WHEREAS, in recent years there has been a significant increase in the concern over the health and safety aspects of high voltage transmission lines; and

WHEREAS, a joint subcommittee established pursuant to Senate Joint Resolution No. 26 of the 1984 Session of the General Assembly carefully studied the health and safety aspects and heard from a number of experts who were not in agreement over whether harmful effects exist; and

WHEREAS, currently there are a large number of studies on the health and safety of such lines, the result of which the joint subcommittee feels should be continuously monitored so that if any causal relationships develop the General Assembly will be informed and will be able to take appropriate action to protect the citizens of Virginia; and

WHEREAS, it is the sense of the joint subcommittee that this monitoring could best be done by the State Corporation Commission, which by statute has oversight over the construction of transmission lines, and the Department of Health; now, therefore, be it

RESOLVED by the Senate, the House of Delegates concurring, That the State Corporation Commission and the Department of Health are requested to monitor the ongoing research on the health and safety effects of high voltage transmission lines; and, be it

RESOLVED FURTHER, That the Department of Health, after consultation with the State Corporation Commission, is requested to report its findings annually to the General Assembly.

Appendix B

Senate Joint Resolution No. 278

Requesting the State Corporation Commission and the Department of Health to include studies pursuant to the Energy Policy Act of 1992 in their monitoring of research to determine whether electric and magnetic fields affect human health.

Agreed to by the Senate, February 9, 1993
Agreed to by the House of Delegates, February 17, 1993

WHEREAS, Senate Joint Resolution No. 126 (1985) requested the State Corporation Commission (SCC) and the Department of Health (DOH) to monitor ongoing health and safety research relating to high-voltage electric transmission lines and requested DOH, after consultation with the SCC, to report its findings annually to the General Assembly; and

WHEREAS, the General Assembly has received six such annual reports reviewing the extensive research related to the subject; and

WHEREAS, public interest in this subject has continued; and

WHEREAS, the Federal Energy Policy Act of 1992 requires the Secretary of Energy to undertake a comprehensive five-year study to determine whether electric and magnetic fields produced by the generation, transmission and use of electric energy affect human health and authorizes an appropriation of $65 million, to be supplemented by nonfederal sources, for that purpose during the years 1993-1997 so that action, if any, to be taken by the federal government can be based upon scientifically valid research; and

WHEREAS, the Department of Energy, the National Institute of Environmental Health Sciences, the Environmental Protection Agency, the Department of Defense, the Occupational Safety and Health Administration, the National Institute of Standards and Technology, the Department of Transportation, the Rural Electrification Administration and the Federal Energy Regulatory Commission will participate in the study, and the National Academy of Sciences will periodically evaluate the progress of the study; and

WHEREAS, that Act provides for the establishment of the National Electric and Magnetic Fields Advisory Committee to advise the Secretary of Energy with respect to the design and implementation of the study; the committee shall be composed of ten members including representatives of state health agencies and state regulatory agencies as well as other experts in the field; and

WHEREAS, the results of the study, as well as information compiled during the course of the study, may be useful to the General Assembly; now, therefore, be it

RESOLVED by the Senate, the House of Delegates concurring, That the SCC and DOH, with assistance from the Medical College of Virginia, be requested to continue to monitor relevant on-going research as described in SJR 126 and to submit annual reports thereon; and, be it

RESOLVED FURTHER, That as part of the foregoing activity, the SCC and DOH be requested to monitor and, if feasible, participate in the study of electric and magnetic fields pursuant to the Energy Policy Act of 1992.

Appendix C

Previous Reports in the Series

1. Health Effects of High Voltage Transmission Lines, August 15, 1984.

2. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines, September 25, 1985.

3. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Second Annual Report), November 13, 1986.

4. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Third Annual Report), October 23, 1987.

5. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Fourth Annual Report), December 5, 1988.

6. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Fifth Annual Report), March 15, 1990.

7. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Sixth Annual Report), January 10, 1991.

8. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Seventh Annual Report), March 10, 1992.

9. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Eighth Annual Report), March 24, 1993.

10. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Ninth Annual Report), April 20, 1994.

11. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Tenth Annual Report), March 14, 1995.

12. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Eleventh Annual Report), February 26, 1996.

13. Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines (Twelfth Annual Report), March 20, 1997.